Effect of Extrinsic Fuel Moisture Content on the Performance of Bagasse Boiler for Suspension Combustion

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Abstract: Sugars cane factory use the fibrous content in the cane after grinding it (bagasse) as a fuel to produce the energy needed for their process. Our contribution has focused on the presentation of the effect of fuel moisture content on steam production in the boiler. We started with the influencing of the variation of bagasse moisture content with fossil fuel used in the boiler and the downtime periods during heavy rainy seasons. A study of the influence of the fuel moisture content to the NCV (Net Calorific Value) and GCV (Gross Calorific Value) was done. Subsequently, we introduced the action of moisture on the temperature, pressure and flow rate of the steam leaving the boiler. Also were done the combustion analysis. Our results indicate that when the bagasse moisture content exceeds 50% which correspond to the maximum humidity rate admissible in the bagasse furnace, there is increased consumption of fossil oil and or stop production. For the same values of moisture, there is decrease in the amount of energy released per kilogram of fuel, there’s variation contributed to deteriorate steam produced in its quality and quantity resulting on downtime. The excess air is 116% resulting on the incomplete combustion by mechanical and chemical loss, and high smoke production. Then, the designer of bagasse boiler should take into account the effect of extrinsic fuel moisture content.

Keywords: Bagasse, extrinsic moisture rate, combustion, steam, boiler.

Nomenclature:

- Ar: Argon
- C: Carbon
- CO₂: Carbon dioxide
- GCV: Gross Calorific Value (kcal/kg)
- H₂: Dihydrogen
- H₂O: Water bagasse content
- O₂: Dioxygen
- k: Bagasse ash content
- Mₐ: Comburivore mass power
- Mₐₑ: Molar mass of air (kg/kmole)
- Mₙ: Molar mass of bagasse (kg/kmole)
- mₘₑ: Mass bagasse ashless (kg)
- Nₐ: Comburivore molar power
- N₂: Diazote
- NCV: Net Calorific Value (kcal/kg)
- o: Moisture content on bagasse (kg/kg)
- a, b, c, d, e, f, g, h, j: Auxiliary variables
- t/h: Tone/hour
- y_c, y_H₂, y_O₂, y_H₂O: Mass fractions of carbon, dihydrogen, dioxygen and water respectively

1. Introduction

Sugar cane industry is one of the few industries which produce energy (mechanical, electrical and thermal) necessary for their operations which surplus can be export to the grid (increase their income). In fact, the sugar cane bagasse, which is the fibrous residue obtained after crushing cane to extract the juice [1] is used as fuel in boilers [2]. This combustion allows producing steam for use in the production of different forms of energy. When in countries like Brazil and
Cuba, we talk about optimization of the production of electrical energy and surplus export to the grid [3-5], in Africa Tropical Regions and Cameroon the problem still remain on combustion stability. Indeed, the poor quality of the steam obtained on heavy seasonal rain often causes downtime. For properties of the fuel, it is the moisture content which is most important for wet combustion. This moisture content is defined in two forms, the extrinsic and intrinsic moisture. The first does not take into account the weather conditions and represents the laboratory values while the second takes into account it [6]. So many researchers[1-2, 7] which work on bagasse combustion with moisture rate between 48 % and 50 % preconize the using of some excess (between 30 % and 50 %) air for reduction losses by incomplete combustion (mechanical and chemical causes). This excess air added to the water evaporated during combustion cooled and increases the volume of gas in the chamber. Latent heat of vaporization water content in bagasse is lost with flue gases. The cooling chamber increases the radiative and convective losses exchange due to erosion and corrosion of water pipes done by the lower flame temperatures [4, 8-13]. It is also known that the amount of evaporated fuel in the 48 % humidity is lower than the water quantity evaporated by the same fuel at 50 % moisture and more. This problem was posed by [14] for pile and stoker combustion. Several configurations (furnace) of boilers were then subsequently proposed and today we talk about suspension or fluidized bed combustion with air and water (economizer) preheater [4-5, 15]. For the designer, the variation of moisture content (increase 4 % to 5 %) disturbed the combustion [16]. This configuration allows the fuel to dry for his fall on the furnace before burning on or near the grid. So extrinsic moisture content is not take into account by researchers and designers of boilers. The objective of our work will be to present the effect of extrinsic moisture on the boiler for suspension burning performance of the Nkoteng plant for Sugar Company of Cameroon. More specifically, we will collect the bagasse moisture content during the months of May and June with the pressures, temperatures and flow rates of steam produce by the boiler to make a comparative study.

2. Material and Methods

2.1 Physical Characterization

A drying oven Memmert brand, construction No. D91107 Schwabach and an electronic balance Sartorius brand, 1264 type have been used to determine the moisture content on the bagasse [17]. For determining the GCV (Gross Calorific Value) and NCV (Net Calorific Value) of the bagasse, we used the Eqs. (1) and (2) given by [1]. Considering 2 % sugar content on bagasse and for each value of moisture, NCV and GCV were evaluated.

\[
\text{NCV} = 4226 - 4850\omega \quad \text{(kcal/kg)} \quad (1)
\]
\[
\text{GCV} = 4600 (1 - \omega) - 2400 \quad \text{(kcal/kg)} \quad (2)
\]

Verification of the quality of the steam was made by taking the moisture of the fuel rate, and at each humidity rate data of steam pressure and temperature leaving the boiler were collected. Regarding the amount of steam, humidity rate data were collected and the corresponding flow steam.

2.2 Boiler

The boiler shown in Fig. 1 has the same configuration as that of the Nkoteng plant. It is on this boiler that we have taken pressures, temperatures and flow of steam to our study. In addition to its combustion chamber, it is constituted by an economizer (water preheater) and a combustion air preheater. This is a boiler type: BR2 43/68. The construction features are presented in Table 1.

2.3 Combustion Analysis

The combustion analysis consists on the determination of comburivore power, CO\textsubscript{2} rate in the flue gases and excess air rate allowed in the combustion chamber [17].

First, we began by calculating the mole fractions (\(y_{ab}\))
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Table 1  Parameters for design consideration.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum steam produced per hour rate</td>
<td>45 t/h</td>
</tr>
<tr>
<td>Steam temperature at the outlet</td>
<td>390 °C</td>
</tr>
<tr>
<td>Pressure steam output</td>
<td>31 bars</td>
</tr>
<tr>
<td>Fuel Type</td>
<td>Bagasse</td>
</tr>
<tr>
<td>Moisture content of the fuel</td>
<td>50 %</td>
</tr>
<tr>
<td>Ash content of the fuel</td>
<td>2 %</td>
</tr>
<tr>
<td>Sugar</td>
<td>2.5 %</td>
</tr>
</tbody>
</table>

Actual reaction: (wet bagasse) + (humid air) with formation of CO and C in the combustion product.

\[ y_C + y_{H_2} + y_{O_2} + y_{H_2O}H_2O + k + a[3.718N_2 + O_2 + 0.044Ar] \rightarrow bCO_2 + cCO + dCO_2 + eH_2O + (4) \]

\[ \text{CO}_2 = \frac{\text{CO}_{2\text{max}}}{100} [100 - 4.78O_2 + 189CO] - \text{CO} \]  

\[ M_a = N_a \frac{M_{\text{air}}}{M_b \times m_b} \]  

\[ N_a = \frac{n_{\text{air}}}{n_b} \]  

\[ M_f = M_a (1 - w)E + 1 \]  

\[ E = \frac{\lambda - 1}{R} \]  

\[ \lambda = \frac{1}{R} \left( \frac{N_a}{n_{\text{air}}} \right) \]  

It therefore requires the knowledge of the smoke content of oxygen and carbon monoxide. These values were taken from factory data.

From the result of comburivore power, we used the Eq. (8) developed by [1], expressed as a function of bagasse moisture and excess air fuel ratio to determine smoke-producing capacity.

3. Results and Discussion

Figs. 2-3 show the influence of extrinsic humidity on the bagasse boiler performances. These figures show three bands, one representing the (blue) humidity, the other oil consumption (red) and the third stop burning times (green) or production down times. We observe the regular humidity rates (48 % to 50 %) with poor consumption of fossil combustible and regular production without down time from 1st to 19th May. This period correspond on the transition between dry and rain season. From 20th to the end of the month, we observe that the bagasse moisture content is higher than 50 %. This situation induces the fossil fuel consumption and downtime. On the June month, the humidity rate is usually superior on 50 % corresponding on excess fossil fuel consumption and greater downtime than the half of May. Then, when the humidity rate is above 50 %, the operator either stop the boiler or add the fossil fuel to stabilize and enable combustion. This fluctuation of humidity is more pronounced during the month of June, months of strong rainy season.
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These multiple stops or increased fuel consumption are cause by the losses by unburned solids. Indeed, as shown in Figs. 4-5, the increase in the bagasse moisture introduced into the boiler decreases the amount of heat released per ton of fuel. This justifies the introduction of the fossil fuel in the combustion chamber to maintain it constant. And when the phenomenon increases, the combustion is simply stopped.

The consumption of fossil fuel is intended to regulate the amount of energy released by the fuel and indirectly regularize steam pressure due to cooling of the combustion chamber.

This cooling reduces the heat transfer of the heat from the combustion chamber to the water in the tubes.

This steam with excess air introduced into the chamber escape in dry flue taking the sensible heat. Then we observed pressure drop of the steam output of the boiler (Fig. 6). This fall becomes more pronounced when the moisture content on the bagasse is greater
Regarding the temperature of that steam, there is a less stable (330 °C) for less than 50 % humidity rate. At 51 %, there is sudden drop in temperature before the lift but to oscillate around a slightly lower value (320 °C) with greater amplitude and irregular. The fall is due to the fact that the humidity rate of bagasse is exceeded the maximum value admissible in the boiler. This requires the operator to administer the fossil fuel and bagasse from storage to the furnace for stabilizing and regulating it. From the above 53.5 % moisture, oscillations around 310 °C corresponding to the downtime are observed.

These conjugates of the pressure and temperature of the steam behavior demonstrate the sensitivity of the bagasse moisture content variation introduced into the furnace on the quality of the steam produce.

These facts justify the combustion instabilities that cause the poor quality and quantity of steam and downtime during heavy rainy seasons.

The previous curve (Figs. 7-8) shows has three parts. The first portion is between 48 % and 49 % moisture content of the bagasse. In this portion, is observed that the delivery of steam is constant and equal to 44 tones/hour. The second part is limited by the humidity from 50 % to 52 %, in the lower portion of the flow of steam from 45 tones/hour to 25 tones/hour was observed. The last part corresponds to greater than 53 % humidity rate in this portion of a control flow of the steam was observed at 25 tones/hour.

The three portions observed is the same with those observed on the pressure and temperature of the steam (Fig. 7). Regulation obtained between 50 % and 53 % corresponds to the consumption of fossil fuel. The third portion in turn corresponds to downtime or combustion stop.

From the combustion analysis and moles fraction determination and we get:

\[0.27C + 0.229H_2 + 0.1O_2 + 0.394H_2O + K\] + 
\[1.120N_2 + 0.302O_2 + 0.0133Ar + 0.028H_2O\] $\rightarrow$ 
\[0.078C + 0.0189CO + 0.173CO_2 + 0.651H_2O + 0.0217O_2 + 1.133N_2 + 0.0133Ar + K\]  

The Table 2 shows us that the comburivore power is similar to that given by [1]. The slight difference is due to the fact that our bagasse is a little wet than it so requires more air. The result of CO2 found in the table is in the range given by [1]. Fair limit is justified by the incomplete combustion that takes place in our boiler. Indeed, some carbon particles could not be oxidized and are still found in the flue gases as carbon monoxide.
Table 2  Results from combustion analysis.

<table>
<thead>
<tr>
<th>Designations</th>
<th>Symbols</th>
<th>Corresponding results</th>
<th>Comparison [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comburivore power (M a)stoc</td>
<td>(Mₐ)ₜₙₜ₀</td>
<td>5.96</td>
<td>5.76</td>
</tr>
<tr>
<td>CO₂ rate on the combustion products (%)</td>
<td>CO₂</td>
<td>12.12</td>
<td>12 to 16</td>
</tr>
<tr>
<td>Rates of excess air (%)</td>
<td>E</td>
<td>116</td>
<td>25 to 60</td>
</tr>
<tr>
<td>Smoke developed (kg/kg)</td>
<td>Mₙ</td>
<td>6.57</td>
<td>5.5</td>
</tr>
</tbody>
</table>

(CO) and carbon (C). These particles increase the gas volume and losses by incomplete combustion.

The excess air rate is determining using the standard reaction equation for incomplete combustion; the result is far from the limits established by [1] (see Table 2). This discrepancy is explained by the desire of the factory operator to limit losses by incomplete combustion with the formation of CO instead of CO₂ (chemical cause) and losses with remaining unburned bagasse (mechanical cause). This excess air added loss by incomplete combustion with the formation of CO₂ instead of CO increases the gas volume and cool the combustion chamber.

Obtaining Smoke Power show that it is slightly higher than that obtained by [1] (see Table 2). The difference is due to the high excess air rate admitted into the furnace, the amount of water vaporized on the bagasse and after the transformation of the hydrogen molecule in water evaporated during combustion. Smoke production becomes a critical parameter in quality (temperature and composition) and quantity.

4. Conclusions

Our work was to present the effect of fuel moisture content on it combustion from suspension burning. The results presented in this document indicated us that when there’s fluctuating of bagasse moisture content values exceed 50 %, there have increased consumption of fossil fuels and/or downtime. The increase in humidity leads to the fall of the amount of energy released per kilogram of bagasse burned. This is not without consequences on the quality and quantity of steam produced which is degrades. In fact, when the bagasse moisture content exceeds 50 % we observe the pressure drop (from 28.6 bars to 24.9 bars) and oscillation of the temperature of steam produce. The combustion analysis shows an excess air rate of 116 %.

Following the rate of CO₂ in the combustion products, it is sure that the Carbone molecule is still remain on these products. Then, the designers of boiler for suspension burning technology should takes into account the extrinsic fuel moisture content. The study (quality and quantity) of the loss which occurred in the boiler should be study and possible dehydration of bagasse before burning to complete our analysis.

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